TECHNICAL MEMORANDUMS

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

No. 293

NOMOGRAM FOR CORRECTING DRAG AND ANGLE OF ATTACK OF AN AIRFOIL MODEL IN AN AIR STREAM OF FINITE DIAMETER.

From Report A 58 of the "Rijks-Studiedienst voor de Luchtvaart," reprinted from "De Ingenieur," September 20, 1924.

December, 1924.

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NOMOGRAM FOR CORRECTING DRAG AND ANGLE OF ATTACK OF AN AIRFOIL MODEL IN AN AIR STREAM OF FINITE DIAMETER.*

1. Object of the Nomogram.

In experimenting with airfoil models in a wind tunnel, the magnitude of the forces acting on the model is affected by the fact that the air stream in which the model is suspended, has a restricted cross-section. In order to utilize the results for an airplane in an unlimited quantity of air, a correction must be made. For the customary ratios of the dimensions of the models to the cross-section of the tunnel, corrections need to be made for the angle of attack and the drag (apart from the force of the wind parallel to the direction of flow). The magnitude of this correction was determined by Prandtl by the application of his wing theory.** For an air stream of circular cross-section the drag correction is

$$R_x' = \frac{C_y^2 \frac{\rho}{g} S^2 V^2}{4 S_T} \left[1 + \frac{3}{16}\left(\frac{c}{D}\right)^4 + \frac{5}{64}\left(\frac{c}{D}\right)^8 + \ldots\right]$$

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* Report A 58 of the "Rijks-Studiedienst voor de Luchtvaart," reprinted from "De Ingenieur," of September 20, 1924, pp. 29-33.

** L. Prandtl, "Tragflügeltheorie," II Mitteilung. "Nachr. v. d. Kön. Ges. d. Wissensch. zu Göttingen." Math. Phys. Kl. 1919, No.1, p. 107. Also "Ergebnisse der Aerodynamischen Versuchsanstalt zu Göttingen," I Lieferung, p. 43; II Lieferung, p. 17.

Nomogram for Drag Correction C_x'.

$$x = C_y$$

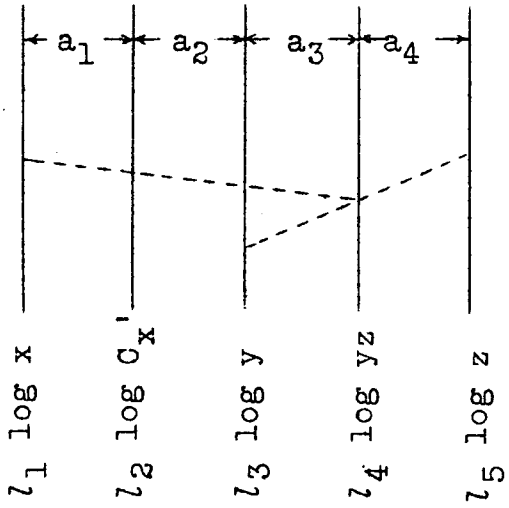
$$y = \frac{S}{4\ S_T}$$

$$z = 1 + \frac{3}{16}\left(\frac{c}{D}\right)^2 + \frac{5}{64}\left(\frac{c}{D}\right)^4$$

$$a_1 = a_2 = a_3 = a_4$$

$$l_2 = \frac{1}{3}\ l_1\ ;\ l_3 = 2l_1\ ;\ l_4 = l_1\ ;\ l_5 = 2l_1$$

Fig.1.



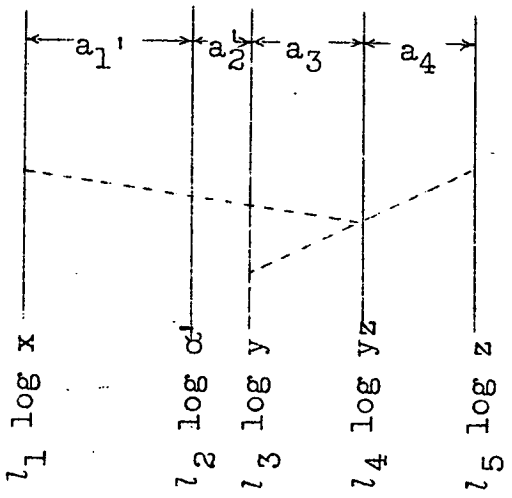
Nomogram for Angle of Attack Correction α'.

$$a_1' = \frac{3}{2}\ a_4;\ a_2' = \frac{1}{2}\ a_4;\ a_3 = a_4$$

$$l_2' = \frac{1}{2}\ l_1$$

Above values of l, x, y and z as in Fig. 1.

Fig.2.



A non-dimensional coefficient can be found for this correction, the same as for the above forces.

$$C_x' \quad \frac{C_y^2 S}{4 S_T}\left[1 + \frac{3}{16}\left(\frac{c}{D}\right)^4 + \frac{5}{64}\left(\frac{c}{D}\right)^8 + \ldots\ldots\right] \quad (1)$$

In the case under consideration, the correction for the angle of attack is

$$\alpha' = 57.3 \frac{C_y S}{4 S_T}\left[1 + \frac{3}{16}\left(\frac{c}{D}\right)^4 + \frac{5}{64}\left(\frac{c}{D}\right)^8 + \ldots\ldots\right] \quad (2)$$

The symbols employed in the formulas and in the above nomogram have the following significations:

C_y = absolute lift coefficients;

C_x' = correction for absolute drag coefficients;

$C_{x\ meas.}$ = absolute drag coefficient (measured);

C_x = absolute drag coefficient (corrected);

ρ = air density in kg/m^3;

g = acceleration due to gravity in m/sec.^{2};

S = area of wing in m^2;

S_T = area of tunnel cross-section in m^2;

V = wind velocity in m/sec.;

c = chord in m;

D = diameter of tunnel in m;

$\alpha_{meas.}$ = angle of attack measured in degrees;

α' = correction of angle of attack in degrees;

α = actual angle of attack in degrees.

The corrections were made according to the formulas:

$$C_x = C_{x\ meas.} \pm C_x'$$

$$\alpha = \alpha_{meas.} \pm \alpha'$$

The signs for C_x' and α' depended on the type of wind tunnel in which they were measured, being positive in a closed tunnel and negative in an open tunnel.

The object of this nomogram is to enable the direct reading of the corrections C_x' and α'.

2. Description of Nomogram.

The nomogram for a product of the form $z = x^m y^n$ consists of three parallel lines provided with logarithmic scales. Two points on the x and y scales are connected by a straight line. The point of intersection of this line with the third parallel then gives the corresponding value of z. The value of the constant ex-

ponents m and n is then determined by the ratio of the mutual distances of the parallel lines and of their lengths (found on the different scales) for logarithmic unity.*

This method can also be employed for products of more than two variable factors. In this case the product of two terms is first found, which is then combined with the following term, and so on.

The corrections given in formulas (1) and (2) may be considered as products of the form

$$C_x' = x^2 y z \quad \text{and} \quad \alpha' = xyz, \quad \text{in which} \quad x = C_y, \; y = \frac{S}{4 S_T}$$

and $$z = 1 + \frac{3}{16}\left(\frac{c}{D}\right)^2 + \frac{5}{64}\left(\frac{c}{D}\right)^4.$$

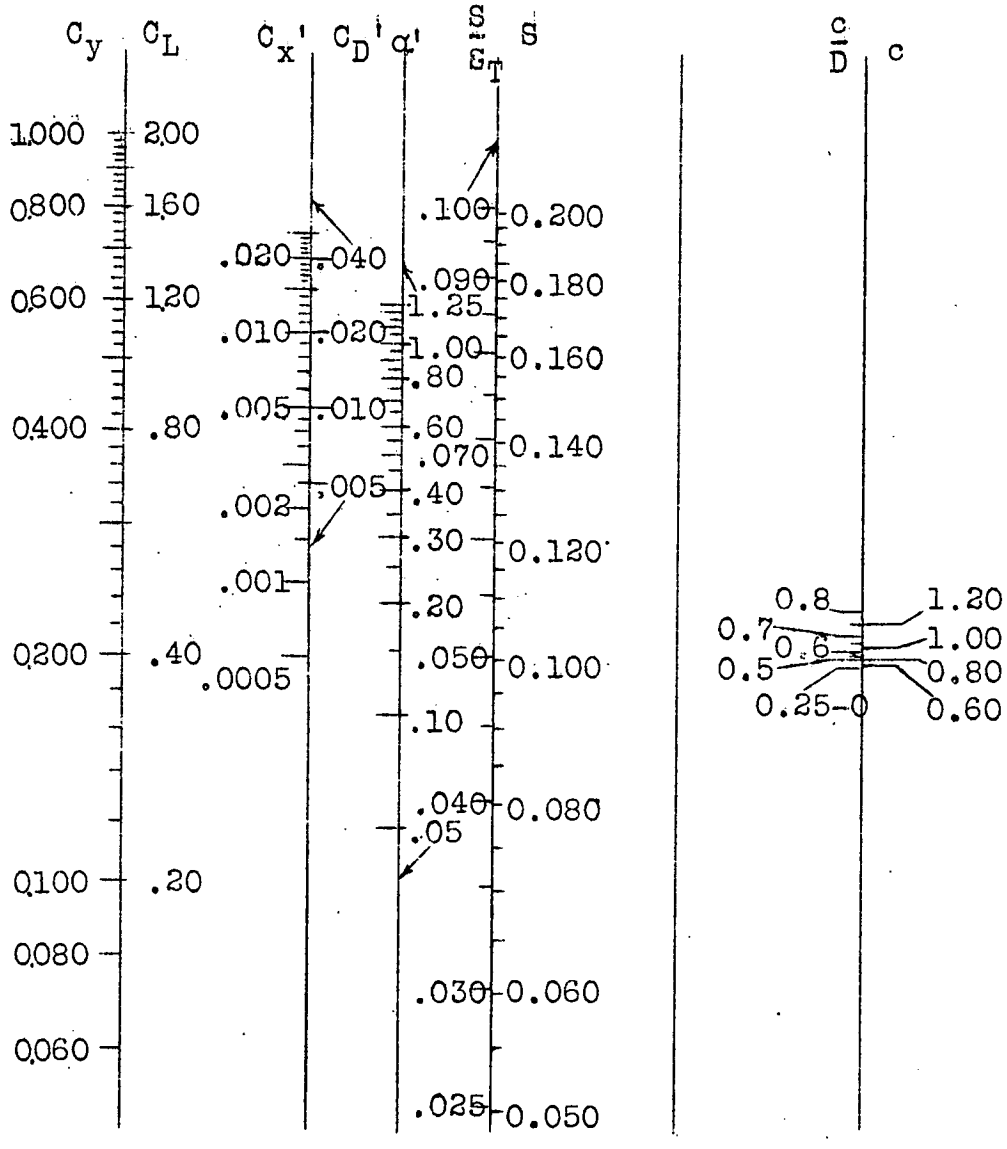
Figs. 1 and 2 show diagrammatically how the nomograms for these products are made up. In each case the dash line shows the course of the "calculation." The combining of the two figures gives the complete nomogram as shown in Fig. 3. Herein the scales y and z are not divided according to the values of these quantities, but according to the values of S/S_T and c/D. If the nomogram is employed for a given wind tunnel, i.e., for fixed values of S_T and D, then these scales are divided directly into S and c. In Fig. 3, for example, these scales are employed for the wind tunnel

* For the theory of this type of nomogram, known as the "nomogram with alined points," you are referred to:
R. Soreau, "Nomographie," Vol. I, p. 174.
D'Ocagne, "Principes usuels de nomographie," p. 14.
C. Runge, "Graphische Methoden," p. 73.
Dictionary of Applied Physics, Vol. III, p. 635.
"Handworterbuch der Naturwissenschaften," Vol. V, p. 113.

of the R. S. L. in which S_T = 2.01 m^2(21.64 sq.ft.) and D = 1.6 m (5.25 ft.). Both scales for the coefficients are provided with divisions employed in the most common systems. C_y and C_x' are the coefficients hitherto employed by the R.S.L. and the N.P.L. C_L and C_D' are values which are two times as large (Göttingen).

Nomogram for Drag Correction C_x' and Angle of Attack Correction α'

Fig.3.



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